Dynamics of Suspended Sediments in an Optically Deep Coastal Region

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LONG-TERM GOALS

The long-term goals associated with this project are to understand the suspension, transport, and deposition of fine sediments and their effect on optics in coastal regions.

OBJECTIVES

The specific objectives of this project are (1) to obtain direct oceanic measurements of the upward flux of fine sediments due to turbulence and the corresponding downward flux due to gravitational settling; (2) to test observationally the nearly universal assumption that fine sediments are transported vertically by turbulence in the same manner as heat (i.e., that turbulent Schmidt and Prandtl numbers are equal); and (3) to quantify observationally the relationship between the upward flux of fine sediments from the seafloor and the bottom stresses produced by waves and currents.

APPROACH

The approach requires measurements obtained by a near-bottom array of acoustic Doppler velocimeters (ADVs) (e.g., Voulgaris and Trowbridge, 1998), manufactured by Sontek, Inc., and a nearby array of Laser In-Situ Sizing and Transmissometry (LISST) sensors (Agrawal and Pottsmith, 2000), manufactured by Sequoia Scientific, Inc. ADVs measure the three-dimensional velocity vector and the acoustical backscatter intensity in a sample volume with a scale of 1 cm. LISSTs measure particle size distribution, and a modified LISST with settling tube (LISST-ST) measures settling velocity as a function of particle size. ADV measurements permit calculation of ensemble-averaged (in this case, hour-averaged) acoustical intensity, denoted $< I >$, and covariance of vertical velocity and acoustical intensity, denoted $< I'\omega' >$. The idea is that LISST and LISST-ST measurements of particle size distribution and density will determine proper interpretation of the acoustical measurements, permitting meaningful computation of the upward flux of sediment due to turbulence, $\sum < c'_n\omega' >$, as well as the downward flux due to settling, $\sum \omega_{sn} < c_n >$. Here C_n is sediment concentration in the nth size class, ω_{sn} is the corresponding settling velocity, primes denote turbulent fluctuations, brackets denote hour averages, and summation is over all size classes. Measurements of $\sum < C'_n\omega' >$ and $\sum \omega_{sn} < C_n >$ will permit evaluation of the hypothesis that turbulent Schmidt and Prandtl numbers are equal and quantification of the relationship between bottom stress and sediment flux from the seafloor.

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WORK COMPLETED

This project is a collaborative effort with Y. C. Agrawal, of Sequoia Scientific, Inc., who is funded under a separate grant. The primary focus of the collaboration is participation in the 2000 and 2001 Hyperspectral Coupled Ocean Dynamics Experiments (HYCODE) at Rutgers University's LEO-15 site off New Jersey.

During the 2000 experiment, Trowbridge designed and supervised fabrication and deployment of a bottom tripod supporting ADVs at 0.7 and 3.5 m above bottom, fast-response thermistors near the ADV sample volumes, and a temperature-conductivity sensor at 4.5 m above bottom. Agrawal designed and supervised fabrication and deployment of a bottom tripod supporting a LISST at 2.0 m above bottom, a LISST-ST at 1.0 m above bottom, and a Miniature Scattering and Transmissometry (MSCAT) sensor at 0.2 m above bottom. Deployment of both tripods occurred during July near the main node at LEO-15, at a position where the mean depth is 16 m and the sand bottom is flat except for wave-formed ripples. Recovery occurred in September.

During the 2001 experiment, Trowbridge and Agrawal redeployed the two tripods at LEO-15. Trowbridge added a dop-beam, which measures vertical velocity and echo intensity at high frequency (375 Hz) and high resolution (0.012 m) along a vertical path with a range of 1.5 m. The dop-beam measurements will provide far more information about vertical flux of suspended sediments than will the ADVs.

Work during 2002 and 2003 has focused on analysis of the 2000 and 2001 data sets. In addition, work during 2002 and 2003 has addressed analysis of near-bottom ADV and LISST measurements obtained during the ONR-funded Coastal Mixing and Optics (CMO) experiment, which occurred during 1996-97 in the ``mud patch'' on the New England shelf, and on analysis of laboratory measurements that have been published in the scientific literature. As part of CMO, A. J. Williams, of the Woods Hole Oceanographic Institution, deployed a bottom tripod with an array of three ADVs, all at a height of 0.4 m above bottom, and Y. C. Agrawal deployed a nearby tripod with a LISST. Laboratory measurements that have been published in the scientific literature provide information regarding fluid velocities and sediment concentrations that is useful for testing ideas about the dynamics of suspended sediments.

RESULTS

This section describes only the results on which Trowbridge has taken the lead role. Results for which co-PI Agrawal has taken the lead role are summarized separately in Agrawal's report.

An important focus of the analysis has been field and laboratory evaluation of a striking feature that is common to modern models of the dynamics of suspended sediments: if the sediment supply is large enough, then the particle concentration is limited not by the supply but by the suspended load that the flow can carry. In essence, at large supply the flow becomes "saturated" with sediments, and the saturation condition sets an upper bound on sediment concentrations. This feature is important because it eliminates the heavy dependence of older models on the poorly constrained bottom boundary condition for suspended sediments, and leads to quantitative, testable predictions.

Both field measurements and laboratory measurements indicate quantitative success of the saturation concept. In both the field and laboratory tests, the measured velocity field is combined with the saturation model to determine an upper bound on the sediment concentration field. This upper bound is then compared with measurements of particle concentrations. For fine sediments (settling velocity smaller than the scale characterizing the turbulence intensity), agreement between the model and the measurements is surprisingly good in both the field (Figure 1) and laboratory (Figure 2) cases. For coarse sediments (settling velocity smaller than the scale characterizing the turbulence intensity), the saturation model fails (Figure 2). These results are described by Trowbridge and Agrawal (in preparation) and Trowbridge (in preparation).

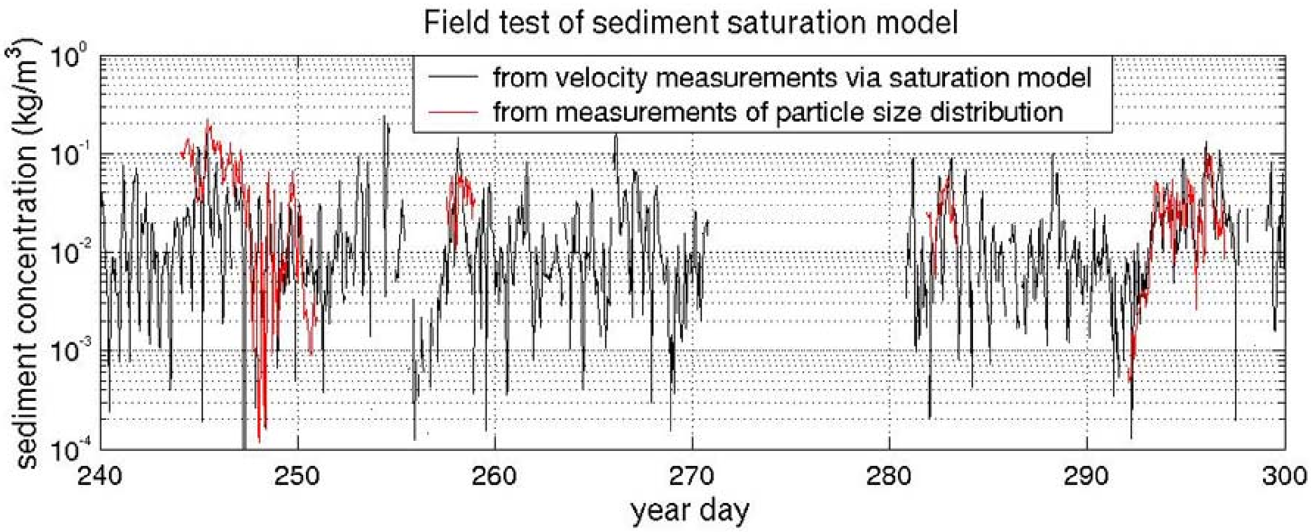

Figure 1. Field evaluation of the sediment saturation model. In this evaluation, the departure of measured velocity gradients and Reynolds stresses from the "law of the wall" (the relationship between stress and velocity gradient that holds in unstratified flows) provides an estimate of the sediment concentration required to explain the observed departure, which is compared with observed particle concentrations. The agreement is very good, supporting the upper bound provided by the saturation model as a realizable state for particle concentrations in oceanic flows.

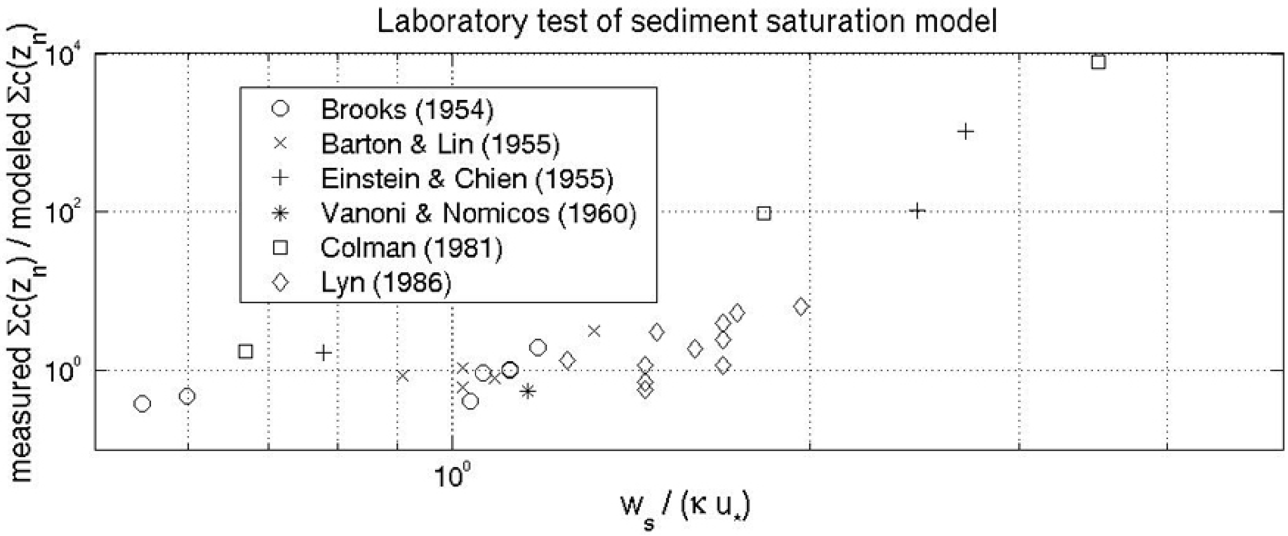

Figure 2. Laboratory evaluation of the sediment saturation model. In this evaluation, measured velocities are combined with the saturation model to determine the maximum sediment concentration that the flow can carry, which is compared with direct measurements of sediment concentration. On the x axis, w_s is the particle settling velocity, kappa is the empirical Karman constant (kappa = 0.40), and u* is the bottom shear velocity, which characterizes the intensity of the turbulence that maintains particles in suspension. The y axis is the ratio of measured to modeled total mass of suspended sediments. The agreement between modeled and measured concentrations is good for fine sediments (w_s/u* less than unity). The model fails for coarse sediments.

IMPACT/APPLICATIONS

Field and laboratory evaluation of the concept that saturation provides a realizable upper bound for particle concentrations in fluid flows will lead to quantitative nowcasts and forecasts of sediment concentrations, which will be valuable in applications involving sediment transport, optics, and acoustics.

RELATED PROJECTS

Trowbridge's and Agrawal's participation in the ONR Coastal Mixing and Optics program have provided techniques and measurements required for execution and testing of the analyses carried out during this study.

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